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Economic Growth and Environmental Quality

Time-Series and Cross-Country Evidence

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It is possible to "grow out of" some environmental problems, but there is nothing automatic about doing so. Action tends to be taken where there are generalized local costs and substantial private and social benefits. Where the costs of environmental degradation are borne by others (by the poor or by other countries), there are few incentives to alter damaging behavior. Trade, debt, and other macroeconomic policy variables seem to have little generalized effect on the environment.

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Shafik and Bandyopadhyay explore the relationship between economic growth and environmental quality by analyzing patterns of environmental transformation for countries at different income levels. They look at how eight indicators of environmental quality evolve in response to economic growth and policies across a large number of countries and across time.

Has past economic growth been associated with the accumulation of natural capital or the drawing down of natural resource stocks? Is the accumulation of physical and human capital a complement to or a substitute for the accumulation of natural capital? How do these relationships vary across different environmental resources? And how have macroeconomic policies affected the evolution of environmental quality? Among their conclusions:

- Income has the most consistently significant effect on all indicators of environmental quality. But the relationship between environmental quality and economic growth is far from simple. As incomes rise, most environmental indicators deteriorate initially, except for access to safe water and urban sanitation — problems that higher incomes help resolve.

- Many indicators tend to improve as countries approach middle-income levels. There is some evidence that countries with high investment rates and rapid economic growth put greater pressure on natural resources, particularly in terms of pollution. But some indicators that worsen with high investment rates, such as deforestation and sulfur oxides, tend to improve with higher incomes.

- The main exceptions to this pattern are dissolved oxygen in rivers, municipal waste, and carbon emissions — all of which have negative effects that can be externalized.

- Technology seems to work in favor of improved environmental quality. Except for fecal coliform, all environmental indicators improve or do not worsen over time, controlling for the effect of income.

- The econometric evidence suggests that trade, debt, and other macroeconomic policy variables seem to have little generalized effect on the environment, although some policies can be linked to specific environmental problems.

- The evidence suggests that it is possible to "grow out of" some environmental problems, but there is nothing automatic about doing so — policies and investments to reduce degradation are necessary. The evidence shows that most countries find such environmental policies and investments worthwhile.

- Action tends to be taken where there are generalized local costs and substantial private and social benefits. Where the costs of environmental degradation are borne by others (by the poor or by other countries), there are few incentives to alter damaging behavior.

Economic Growth and Environmental Quality:
Time Series and Cross-Country Evidence

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1. Introduction

This paper explores the relationship between economic growth and environmental quality by analyzing patterns of environmental transformation at different income levels. Has past economic growth been associated with the accumulation of natural capital or the drawing down of natural resource stocks? Is the accumulation of physical and human capital a complement to or a substitute for the accumulation of natural capital? How do these relationships vary across different environmental resources? And how have macroeconomic policies affected the evolution of environmental quality?

2. The Approach

The theoretical literature on the interaction between economic activity and the environment is advanced.[1] But there is little empirical evidence at a macroeconomic level of how environmental quality changes at different income levels. Compilation of such evidence has been constrained, in part, by the absence of data for a large number of countries. While data remains a problem, the situation is much improved and this paper takes a first step at systematic analysis of what data are available.[2]

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[1] See Kneese and Sweeney (1985) for the most comprehensive survey.

[2] See Appendix A for details.

A number of caveats are in order. The data on environmental quality are patchy at best, but are likely to improve over time with better monitoring. Comparability across countries is affected by definitional differences and by inaccuracies and unrepresentative measurement sites. There is also controversy surrounding some of the explanatory variables used below -- particularly those relating to trade policy and political and civil liberties. At this stage of knowledge, the objective is to open up the empirical debate. This paper is a modest step forward toward a better understanding of the links between the environment and economic growth.

The focus will be on renewable resources, such as air, water and forests. This is largely because the most pressing environmental problems tend to be renewable ones. Moreover, the economic literature on nonrenewables is vast and fairly comprehensive. The intertemporal problem of optimal depletion of a finite resource stock was essentially solved early this century by Hotelling.[3] Subsequent work has built on Hotelling's basic intuition to take issues such as technology, imperfect competition, risk and uncertainty into account.[4]

The problems of renewables have been somewhat more intractable. Conceptually, renewable resources are analogous to human and physical capital. The issue is one of optimally accumulating a stock of natural resources to maximize intertemporal welfare. There is a further complication since natural capital can affect welfare directly, as well as through the production

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[3] Hotelling (1931). Hotelling did not address the externalities associated with the depletion or consumption of nonrenewables, such as pollution from mining or fossil fuel consumption. These externalities, which have to do with the assimilative capacity of renewable "sinks", are the subject of interest here.

[4] For a summary, see Dasgupta and Heal (1979) or Kneese and Sweeney (1985).

process. There is the added problem of irreversibility since the depletion of some resource stocks can cross critical thresholds at which point a species or natural habitat are lost forever. But irreversibility is not unique to natural resource stocks -- both physical and human capital are often characterized by substantial irreversibility (or "putty-clay" in the language of vintage theory). In capital theory, the existence of irreversibility results in greater caution and gradualism in investment decisions.

Because the environment is both a consumption good and an input to production, patterns of resource use at different stages of development will depend, given an endowment, on the income elasticity of demand and supply with respect to different environmental goods and services. This is likely to vary with the costs and benefits associated with changes in environmental quality. The marginal costs of a cleaner environment are conventionally defined as an increasing function of environmental quality (E). The marginal benefits are a function of both the level of environmental quality and of per capita income (Y):

(1) $MC = f(E)$ where $dMC/dE > 0$

(2) $MB = f(E, Y)$ where $dMB/dE < 0$ and $dMB/dY >$ or < 0.

It is not possible to sign the elasticity of benefits with respect to income because a number of different forces are at work. The types of environmental degradation that occur depend on the composition of output, which changes with income. Some income levels are often associated with increases in certain polluting activities -- such as the development of heavy industry. There is a view that rising incomes imply that the value of statistical life or health damage caused by environmental degradation is greater. This would imply increases in marginal benefits as incomes rise. But the poor are often the most exposed and vulnerable to health and productivity losses associated with a degraded environment. For example, air conditioners and better overall health status reduce the consequences of air pollution for the rich. This would reduce marginal benefits as incomes rise. There are some environmental problems where thresholds like survival are at stake (hazardous wastes are an example). Here, the willingness to pay to avert damage is close to infinity and the level of per capita income only affects the capacity, not the willingness, to pay. With other environmental issues, the costs can be externalized (such as, transnational pollution or greenhouse gases) and the private benefits to averting damage are small. There is also the issue of intrinsic values of some natural resources. There is a general perception that higher incomes enable the relative luxury of caring about amenities such as landscapes and biodiversity. But many societies with very low incomes, such as tribal peoples, place a very high value on conservation.[5]

At a theoretical level, it is not possible to predict how environmental quality will evolve with changes in per capita incomes. The question is more tractable empirically where we observe some clear patterns. The evidence suggests that, while there is no inevitable pattern of environmental transformation with respect to economic growth at an aggregate level, there are clear relationships between specific environmental indicators and per capita incomes. Where environmental quality directly affects human welfare, higher incomes tend to be associated with less degradation. But where the costs of environmental damage can be externalized, economic growth results in a steady deterioration of environmental quality.

[5] Davis (1992).

3. Some Basic Relationships

The first step is to explore the basic relationship between environmental quality and income, controlling for any country-specific "fixed effects" such as endowment. Indicators of environmental quality were used as dependent variables in panel regressions using data from up to 149 countries for the period 1960-90.[6] The ultimate sample size depended on the availability of data for the relevant variables. The details on data used are provided in Appendix A. The environmental quality indicators used were the lack of clean water, lack of urban sanitation, ambient levels of suspended particulate matter (SPM), ambient sulfur oxides (SO_2), change in forest area between 1961-1986, the annual rate of deforestation, dissolved oxygen in rivers[7], fecal coliforms in rivers[8], municipal waste per capita, and carbon emissions per capita.[9]

Three basic models were tested -- log linear, quadratic and cubic -- to explore the shape of the relationship between income and each environmental indicator:

(3) $E_i = a_1 + a_2 \log Y + a_3 \text{time}$

(4) $E_i = a_1 + a_2 \log Y + a_3 \log Y^2 + a_4 \text{time}$

(5) $E_i = a_1 + a_2 \log Y + a_3 \log Y^2 + a_4 \log Y^3 + a_5 \text{time}.$

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[6] Cross-section regressions were also tried for a number of years, but the results were less robust. Because the number of observations and the country coverage varied widely across years, the specifications, coefficient estimates and significance levels varied among cross-section regressions. The panel results, however, have greater degrees of freedom and provide more credible results.

[7] Low levels of dissolved oxygen, usually caused by human sewage or agro-industrial effluent, reduce the capacity of rivers to support aquatic life.

[8] High levels of fecal coliforms result from untreated human wastes that often carry disease.

[9] The choice of these variables was largely determined by data availability. There are a number of other environmental indicators, such as lead concentrations or species loss, for which sufficient data is not available to begin to analyze systematically.

Per capita income was defined in purchasing power parity terms.[10] All variables are in logarithms unless otherwise specified in the data appendix. Where city variables were used on the left hand side (in the case of local air pollutants like SPM and SO_2), national income figures were used to proxy city incomes.[11] Interactive dummies for the city and measurement site were also included in the air pollution and river quality regressions.[12] The constant term varied for each country or city to capture country-specific effects. A time trend was added to proxy improvements in technology. The results are reported in table 1.

Access to clean water and urban sanitation are indicators that clearly improve with higher per capita incomes. The addition of the quadratic or cubed terms does not add considerable explanatory power to either the water or sanitation regressions. The time trend is significantly negative in all the regressions, implying that, at any given income level, more people have access to water and sanitation services than in the past. Not surprisingly, access to clean water and to adequate sanitation are environmental problems that are essentially solved by higher incomes. The explanation is fairly straightforward. In the case of water, the private benefits to provision are high (survival is at stake) and the social costs of provision are fairly low relative

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[10] The core model was also estimates using conventional GDP measures and the results were not substantially different, although the PPP measure of income did tend to perform better.

[11] National per capita income is a crude proxy for urban income, but sufficient data is not available on income at the city level. The proxy used here assumes that the ratio of urban to national per capita income remains stable.

[12] City dummies were included when air pollution data was available for more than one city in any country. Site dummies were divided into four categories - city central residential, city central commercial, suburban residential, and suburban commercial. City and site dummies were interactive based on the view that pollution from residential and commercial sites across cities might vary depending on the types of industries, local geography, and other site-specific factors.

to the benefits. With urban sanitation, the private benefits are not as high as with water, but the social benefits are because of the substantial externalities, particularly those related to health, associated with poor urban sanitation.

The case for deforestation is more complex. The first obstacle is the measurement of deforestation. The annual variation in deforestation rates is deceptive since countries that depleted their forests in the past and have slowed down would appear to be doing better than countries with substantial forest resources that have only begun to draw down timber stocks. Looking at a longer period does not resolve the problem since data are not available sufficiently far in the past to capture when some countries were cutting down forests most intensively (in some cases, in medieval times). Recognizing these problems, the disappointing results for both the change in forest area between 1962-86 and the annual rate of deforestation between 1961 and 1986 in table 1 are not surprising. None of the income terms are significant in any specification. The best fit, relatively speaking, is the quadratic form. But one can only conclude from these results that, given the measurement problems, per capita income appears to have very little bearing on the rate of deforestation.

The two measures of river quality tend to worsen with rising per capita income. Dissolved oxygen seems to be linear with a negative slope -- implying a tendency for worsening in river quality with rising incomes. Growing effluent pollution associated with industrialization may play a role in reducing dissolved oxygen at higher incomes. In the case of fecal coliform, the cubic model fits the best -- implying that fecal content of rivers worsens, then improves and then deteriorates again at very high income levels. The initial worsening of fecal content, which occurs up to a per capita income level of about $1,375, is probably associated with growing urbanization and consequent pressures on sanitation. The improvement results when urban sanitation services are introduced. The increase in fecal coliform at high income levels, which begins at an income level of $11,400, is more difficult to explain, but may reflect improvements in water supply systems.[13] Where people are no longer directly dependent on rivers for water, there may be less concern about river water quality.

The elasticity of fecal coliform with respect to income is shown in the top part of figure 2. The positive elasticity at income levels below $1,375 (point B in figure 2) indicates that a rise in income would lead to a rise in the level of fecal coliform. The rise in fecal coliform is more than proportionate to the rise in income below the per capita income of $1,220 (point A in figure 2). Between points A and B the elasticity is positive but inelastic, and thereafter an increase in income would lead to a decline in fecal coliform. Between points C and E, a 1 percent increase in income would imply more than 1 percent decline in fecal coliform. This improvement in fecal content is greatest as per capita income approaches about $3,950 (point D). However, as per capita income continues to increase beyond $11,400 the elasticity switches sign again and a further rise in per capita income would not improve environmental quality as measured by fecal coliform in rivers. Beyond $12,820 (point G) the elasticity of fecal coliform with respect to income is elastic and positive, which implies worsening fecal coliform levels at the highest income levels.

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[13] The cubic shape of fecal content is not an artifact of the functional form. The increase in fecal pollution which occurs at incomes above $11,500 per capita is based on 38 observations from seven rivers in three countries (Australia, Japan and the United States). This is even after some extremely high observations of fecal content from the Yodo river in Japan were dropped from the sample.

Local air pollution follows a "bell-shaped" curve. Suspended particulate matter (SPM), which cause respiratory illness and mortality, are largely the result of energy use. The regressions for SPM in Table 1 indicate that the quadratic model fits best, implying that pollution from particulates gets worse initially as countries become more energy intensive, and then improves. The improvement begins at a per capita income level of around \$3,280. The middle part of figure 2 shows changes in elasticity of SPM with respect to per capita income. SPM is found to be inelastic to changes in per capita income in the range of \$570-\$18,750. Below \$570, a 1 percent increase in per capita income would lead to more than 1 percent increase in the SPM. Above \$18,750 a similar increase would lead to more than 1 percent decline in SPM.

Sulfur dioxides, which affect human health and contribute to ecosystem acidification, are also the product of energy use, particularly the burning of fuels with a high sulfur content. The results in table 1 also confirm a quadratic relationship for sulfur oxides with a turning point of around \$3,670 per capita.[14] The bottom part of figure 2 shows changes in the elasticity of sulfur dioxide concentrations with respect to per capita income. Sulfur dioxide is inelastic to changes in per capita income levels in the range of \$1,100-\$12,240. Below \$1,100 per capita, a 1 percent increase in income results in a more than 1 percent increase in ambient sulfur dioxide. Similarly, the same 1 percent increase in per capita income for an economy with

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[14] This is broadly consistent with the only other estimate of this sort done by Grossman and Krueger (1991). They estimate only the relationship between SO_2 concentrations and income in a cross-section of countries, starting with middle income economies, to evaluate the consequences of trade integration in North America for environmental quality.

income above $12,240 would lead to a more than one percent decline in sulfur dioxide concentrations.

In the case of local air pollution, the pattern seems to be one of an initial deterioration of environmental quality as industrialization and energy intensity increases, followed by an improvement as regulations induce cleaner technologies and fuel switching. Technology, proxied by the time trend, appears to have played a favorable role in making improved local air quality possible at an earlier stage of development. In the case of particulates, ambient air quality improves by about 2 percent a year; ambient sulfur dioxide tends to decline by 5 percent a year.

Municipal waste per capita is one environmental indicator that unambiguously worsens with rising incomes. The log linear specification works the best. Richer cities tend to produce more garbage, the composition of which tends to be very different than poor countries. Unlike air pollution, which is generalized and affects everyone who steps outdoors, solid waste can be disposed of in isolated localities. Because solid waste disposal can be transformed into a localized problem, particularly in areas that are not densely populated or are low income communities, higher incomes are not associated with reductions in waste generation.

Carbon emissions per capita, like solid waste, do not improve with rising incomes because the costs are born externally. The log linear specification has virtually all the explanatory power, although the quadratic and cubic terms are also significant. The turning point on the quadratic specification occurs at over $7 million per capita, an income level that is far from relevant. The explanation for the exponential increase in carbon emissions per capita with rising incomes is a classic free rider problem. There are no major local costs associated with carbon emissions -- all the costs in terms of climate change are borne by the rest of the world. Technology has not helped, evidenced by the insignificant time trend, because no incentives to reduce carbon emissions exist.[15]

4. Patterns of Environmental Degradation

Some very clear patterns of environmental degradation emerge from the previous analysis. They are depicted in figure 1 based on the panel regressions and using the coefficient on the time trend to generate patterns for different years. Some environmental indicators improve with rising incomes (like water and sanitation), others worsen and then improve (particulates and sulfur oxides) and others worsen steadily (dissolved oxygen in rivers, municipal solid wastes, and carbon emissions).

These patterns reflect social choices about environmental quality at different income levels. The functional forms reflect the relative costs and benefits that countries attach to addressing certain environmental problems. Water and sanitation, with relatively low costs and high private and social benefits are among the earliest environmental problems to be addressed. Local air pollution, which imposes external costs locally, but is relatively costly to abate, tends to be addressed when countries reach a middle income level. This is because air pollution problems tend to become more severe in middle income economies, which are often energy intensive and industrialized, and because the benefits are greater and more affordable. Where environmental problems can be externalized, as with solid wastes and carbon emissions, there

[15] It is interesting to note that carbon emissions per unit of capital stock have declined over time as countries have moved to cleaner burning fuels and technologies. But this movement to cleaner fuels has been motivated largely by concerns about local, not global, pollutants. See Diwan and Shafik (1992) for an analysis.

are few incentives to incur the substantial abatement costs associated with reduced emissions and wastes.

But dynamics obviously matter for explaining the patterns -- technological innovations alter the cost-benefit calculus at any point in time. Figure 1 also shows how the patterns have changed for the earliest and latest available dates in each sample. Some indicators have unambiguously improved -- such as water, sanitation, particulates, and sulfur oxides. But others, such as fecal coliform in rivers, have unambiguously worsened over time. Dissolved oxygen and carbon dioxide emissions display no change over time.

There is nothing "optimal" or "suboptimal" about the patterns of environmental degradation observed. The optimality of decisions must be evaluated in light of intergenerational well-being, technological possibilities, environmental regeneration rates, and the existing resource base.[16] But the evidence presented here provides an indication of the average of choices made by countries at different income levels.

5. Environmental Quality and Economic Policy

The previous discussion focused on the evolution of environmental quality with respect to per capita income. The rest of this paper will explore the consequences of policy differences across countries, controlling for the effect of income. The best fits from table 1 are the "core models" around which the subsequent discussion of policy variables will be organized. However, all policy variables were tested with all functional forms to insure that the results were

[16] Dasgupta and Maler (1990).

not affected by the shape of the hypothesized relationship with income. Where results differed across specifications, they are noted below.

5.1 Economic Growth and Investment

Economies experiencing rapid economic growth and investment may have worse environmental quality relative to the average for their income level if regulations are slow to respond to changing circumstances. The case of Korea, which pursued rapid economic growth and industrialization and has a number of environmental problems, is sometimes cited as an example. But if the costs of clean technologies are low for new investments but high for retrofitting, high investing and rapidly growing economies may have better than average environmental quality.

The evidence is presented in tables 2 and 3. In the case of water and sanitation, high aggregate rates of investment (defined as total capital formation as a share of GDP) and growth have no additional effect on environmental quality that cannot be explained by per capita income. The case of deforestation is ambiguous. The regressions for the annual rate of deforestation indicate that high investment rates are associated with more rapid deforestation, but rapid growth rates are not. However, where the left hand side variable is the change in forest area between 1961-86, both the investment rate and the growth rate are insignificant. River quality as measured by dissolved oxygen is unaffected by high investment and growth rates, but fecal coliform levels appear to rise with higher investment and growth rates.

With SPM, high investment rates are insignificant, but rapid growth is clearly associated with reductions in particulate concentrations. Sulfur oxides, in contrast, increase in high investment economies, but are unaffected by the growth rate. The generation of municipal wastes tends to increase with rapid growth, but is not affected by the investment rate. Carbon emissions follow the opposite pattern -- they rise significantly with higher rates of investment, but are not associated with rapid growth.

Energy-linked pollutants, such as carbon and sulphur oxides, tend to be closely linked to investment. This implies that investment in physical capital is complementary to energy consumption and to some kinds of pollution. Investments in pollution abatement equipment would obviously have the opposite effect. Rapid economic growth tends to result in higher levels of municipal waste, but more generalized pollutants that harm human health, like particulates, tend to be lower.

5.2 Energy Pricing

Energy subsidies cause inefficient and excessive energy consumption, with consequent spillovers in the form of air pollution. Because energy subsidies affect a number of different energy types -- from kerosene, coal and oil to nuclear -- it is difficult to quantify their magnitude in any country. Given data availability, the focus will be on electricity, which represents much of the world's energy consumption. Data on electricity tariffs are available for sixty countries for the late 1980s and have been added to the core model in table 4.[17] Results are reported for water, sanitation, river quality and municipal waste for comprehensiveness, but no direct

[17] In order to increase degrees of freedom, some of the regressions were run with the cross-section data on electricity tariffs for 1987 applied to the period 1985-90. This is based on the assumption that tariffs did not change substantially during the period and/or that the short run price elasticity of demand was low and slowed the response to price increases where they might have occurred.

relationship with energy pricing was hypothesized or found. Deforestation is an interesting exception where there is a significant negative sign. Countries with higher electricity tariffs have a lower rate of annual deforestation. This is somewhat counterintuitive since higher electricity tariffs would be expected to encourage the use of virtually free energy sources such as forests. But in fact, the opposite appears to be true.

The results for sulfur dioxide and particulates reveal the importance of energy pricing for reducing local air pollution. Higher electricity tariffs are associated with reductions in ambient levels of particulates and, to a lesser extent, sulfur dioxide concentrations in a specification without a time trend. The addition of the time trend reverses the sign of electricity tariffs in the regression for sulfur dioxide, but not in the case of particulates where the results are fairly robust.[18] The pollution externalities associated with electricity tariffs are very apparent in the case of carbon emissions. Increases in electricity tariffs are associated with significant reductions in carbon emissions per capita. A scatter plot of carbon emissions per capita and per capita incomes reveals that the major outliers are the former centrally planned economies and some of the major oil exporters -- all of which tended to subsidize energy.

5.3 Trade Policy

The relationship between trade policy and environmental quality is much debated.[19] Many environmentalist argue that more open economies are forced to compete by lowering

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[18] It is interesting to note that higher electricity prices have a significantly negative impact on ambient sulfur dioxide in the cubic specification. Electricity prices also have a significantly negative sign under all specifications when the city and site dummies are excluded.

[19] For a survey of the issues, see Low (1992).

environmental standards to reduce production costs. Economists often argue that the gains from trade outweigh the environmental spillovers and that environmental protection costs are a very minor determinant of comparative advantage.

In fact, the impact of trade policy on the environment operates through a number of different and often conflicting channels. More open economies are characterized by greater specialization. Countries do have environmental comparative advantage which will be exploited in more open systems. In aggregate, this will result in welfare improvements, but some regions or countries may experience a worsening of environmental quality. Higher-income, more capital intensive economies will tend to concentrate on capital-intensive and often high polluting industries whereas developing countries will focus on labor-intensive, less polluting industries. Openness and competition also tend to increase investment in new technology, which embodies cleaner processes to meet the higher environmental standards of the technology exporting countries. And open economies may adopt higher environmental standards to meet export demand or because foreign investors incur lower costs by imposing a common standard globally.

Some preliminary econometric evidence for Latin America indicates that more open economies have industrial structures that are more concentrated in cleaner industries.[20] This is consistent with the view that capital-intensive, polluting industries are the ones that have benefited from protection. But there is also evidence of displacement -- the share of polluting industries in Latin America increased after environmental regulations in the OECD became more strict.

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[20] Birdsall and Wheeler (1992).

The first step in testing the importance of openness for environmental quality is the selection of indicators of trade policy. There are now a plethora of indicators of openness in the literature, many of which generate conflicting results.[21] Three different indicators of trade policy were added to the core models - total imports and exports as a share of GDP, Dollar's index of trade orientation,[22] and the parallel market premium (a more generalized measure of distortions).[23] They were chosen because they were available for a relatively large number of countries and because they were empirically-based indicators.

The econometric results are reported in tables 5-7. As nontradables, one would not expect openness to have a major impact on access to water and sanitation or on municipal waste. The regression results confirm this view, with all indicators of trade policy having insignificant impacts on lack of water and sanitation and municipal waste per capita.

In the case of deforestation between 1961-86, none of the trade policy indicators were significant. But the annual rate of deforestation was significantly negatively affected by the parallel market premium and by the share of trade in GDP, although not by the Dollar index (see table 7). This implies that countries that trade more put less pressure on forest resources, perhaps because they have other sources of foreign exchange. In contrast, countries characterized by greater distortions seem to deforest less on an annual basis. These results are fairly inconclusive -- not surprisingly where both the left and right hand side variables are highly imperfect.

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[21] For a survey of the problems with various indicators of trade policy, see Pritchett (1991).

[22] A higher Dollar index implies a more open trade regime.

[23] Documentation of these indicators is provided in the data appendix.

There is some weak evidence that river quality is improved in more open economies. The share of trade in GDP, the parallel market exchange rate, and the Dollar index are insignificant in the regressions for dissolved oxygen. In the case of fecal coliform, the parallel exchange rate and the trade share are insignificant, but the Dollar index is significantly negative -- implying that more open economies tend to have less human waste in their rivers.

The results for local air pollution are mixed. Countries that traded more, as measured by the share of imports and exports in GDP, tended to have lower levels of ambient sulfur dioxide. Sulfur dioxide emissions also tend to increase in countries with substantial distortions, as captured by the parallel market premium, but the significance level is low. The Dollar index was very sensitive to the specification. The coefficient on openness as measure by the Dollar index was significantly positive in the quadratic specification, but insignificant in the linear specification and significantly negative in the cubic specification. It is not possible to draw any strong conclusions from the Dollar index results. But the other measures imply that more open and less distorted economies are likely to have better air quality in terms of sulfur dioxide.

Ambient particulate measures display a similar pattern to sulfur dioxide. The share of trade in GDP is insignificant (but significantly positive in the linear specification and negative in the cubic). The parallel market exchange rate is insignificant under all specifications. The Dollar index is insignificant in the quadratic specification, but significantly positive in both the linear and cubic specifications. At best, there is weak evidence that more open economies have lower levels of ambient particulates.

The results for carbon emissions show clearly that more open and less distorted economies pollute less. The share of trade is consistently insignificant, but the parallel market premium is significantly positive and the Dollar index is significantly negative. These results for carbon emissions are consistent with those for electricity prices, where price distortions worsened environmental degradation.

5.4 Debt

Environmentalists often argue that the burden of debt servicing forces poor countries to excessively degrade natural resources. This is an aggregate version of the argument that the poor have lower discount rates and therefore manage natural resources suboptimally because of their concern with day-to-day survival and their lack of access to credit and insurance markets. Table 8 adds data on debt as a share of GDP to the core model described above to respond to these concerns.

The results indicate that debt per capita has no effect on the majority of measures of environmental quality. There are two exceptions. There seems to be a clear improvement in ambient sulfur dioxide in countries that are more indebted. Carbon emissions, however, are the opposite -- emissions per capita increase with rising indebtedness. Thus indebtedness is associated with some improvement in local air quality, but global pollutants increase. This increase in carbon emissions is equivalent to borrowing from future generations who may bear the costs of climate change.[24]

[24] For a more technical discussion, see Diwan and Shafik (1992).

5.5 Political and Civil Liberties

There is a perception that more open and democratic societies will have better environmental quality because of the public good character of many natural resources. On the other hand, more democratic societies may be subject to greater interest group pressure which could undermine environmental protection. The first obstacle in testing such hypotheses is the measurement of political and civil liberties. Two different measures were used here - an index of political rights, and an index of civil liberties. The political liberties index measures rights such as free elections, the existence of multiple parties, and decentralization of power. The civil liberties index measures freedom to express opinions without fear of reprisal.[25]

The estimates are presented in tables 9 and 10. Political and civil liberties have insignificant effects on access to clean water and sanitation. Greater political and civil liberties are associated with increases in the annual rate of deforestation, but total deforestation over the period 1961-86 was unaffected. River quality as measured by dissolved oxygen improves with increased political liberties, but other measures are insignificant. In the case of local air pollution, more democratic countries have higher levels of ambient sulfur oxides. Particulates and municipal wastes per capita were not affected by either political or civil liberties. Carbon emissions are ambiguous -- with a positive sign in the case of civil liberties and a negative sign for political rights.

The results for political and civil liberties indicate no clear pattern. More democratic regimes tend to deforest more, perhaps because they are more subject to local pressures and

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[25] These indexes are based on Gastil (1989) and are described in more detail in the data appendix.

reluctant to enforce forest protection. But given the uncertainties with respect to deforestation data, any conclusions must be tentative. Sulfur oxides also seem to worsen in more democratic regimes, but river quality as measured by dissolved oxygen tends to improve.

6. Concluding Remarks

The results for income in the core models and the significance of the policy variables are summarized in Tables 11 and 12. Income has the most consistently significant effect on all indicators of environmental quality.[26] But the relationship between environmental quality and economic growth is far from simple. Most environmental indicators deteriorate initially with rising incomes, with the exception of access to safe water and urban sanitation which are essentially solved by higher incomes. But many indicators tend to improve as countries approach "middle income" levels, as evidenced by the negative signs on the quadratic income terms. There is some evidence that economies with high investment rates and rapid economic growth put greater pressure on natural resources, particularly in terms of pollution. But some of the indicators that worsen with high investment rates, such as deforestation and sulfur oxides, tend to improve with higher incomes. The major exceptions to this pattern are dissolved oxygen in rivers, municipal waste and carbon emissions -- all of which have negative effects that can be externalized. Technology, proxied by the time trend, clearly works in favor of improved environmental quality. With the exception of fecal coliform, all environmental indicators improve or do not worsen over time, controlling for the effect of income.

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[26] The exceptions here are deforestation and dissolved oxygen where the effect of income was insignificant.

The elasticity of each environmental indicator with respect to changes in per capita income are provided in table 11. The elasticities (ϵ) are calculated for three income groups -- low, middle, and high -- based on the coefficient estimates of the best fitting functional form:

Linear: $\epsilon = \beta_1$

Quadratic: $\epsilon = \beta_1 + 2\beta_2 \log Y$

Cubic: $\epsilon = \beta_1 + 2\beta_2 \log Y + 3\beta_3 \log Y^2$

where the βs are the coefficients on per capita income reported in table 1.

The environmental variables characterized by linear functional forms -- safe water, urban sanitation, municipal waste, and carbon dioxide emissions -- have constant elasticities over changes in income. Access to clean water and sanitation have elasticities of -0.48 and -0.57 respectively, implying that a 1 percent increase in income results in about 0.5 percent more people in the population are served by improved facilities. Municipal waste has an elasticity of 0.38 with respect to income. The greatest linear income elasticity is carbon dioxide emissions per capita. A 1 percent increase in income results in a 1.62 percent increase in carbon dioxide emissions -- hence the exponentially increasing line in figure 1.

The elasticities for the local air pollutants follow slightly different patterns, although both are quadratic. Particulates increase at low incomes (with an elasticity of 0.69), but begin to decline slowly at middle income levels. Once countries reach high incomes, the decline is rapid. Sulfur dioxides increase with respect to income at twice the rate of particulates (the elasticity at low incomes is 1.23) and continue to rise, albeit more slowly at middle incomes. At higher incomes, sulfur dioxide concentrations decline more quickly than particulates. Thus the inverted "U" shape for sulfur dioxides is later and more peaked than that for particulates.

Fecal coliform is the only cubic shaped environmental indicator, but the elasticities show that the largest effects are at low and middle incomes. There is an initial rapid increase in fecal content of rivers at low income levels, followed by a rapid decline at middle income. Thereafter, there is a slow increase at high incomes.

The impact of the various policy variables is summarized in table 12. Probably the most striking feature of the econometric results is how little some of the policy variables -- such as trade, distortions, and debt -- seem to matter for the evolution of environmental quality. Where the policy variables are significant, it is with respect to a specific environmental variable -- such as the case of higher electricity tariffs reducing carbon dioxide emissions. The results are far from conclusive, but the empirical evidence points to the absence of any generalized effects of trade policy, debt or political regime on the environment.

The evidence suggests that it is possible to "grow out of" some environmental problems. But there is nothing automatic about this -- policies and investments must be made to reduce degradation. The econometric results presented here indicate that most countries do choose to adopt those policy changes and to make those investments, reflecting their assessments of the evolution of the benefits and costs to environmental policy. Action tends to be taken where there are generalized local costs and substantial private and social benefits. Where the costs of environmental degradation are borne by others (by the poor or by other countries), there are few incentives to alter damaging behavior.

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Figure 1 Patterns of Environmental Change and Per Capita Income

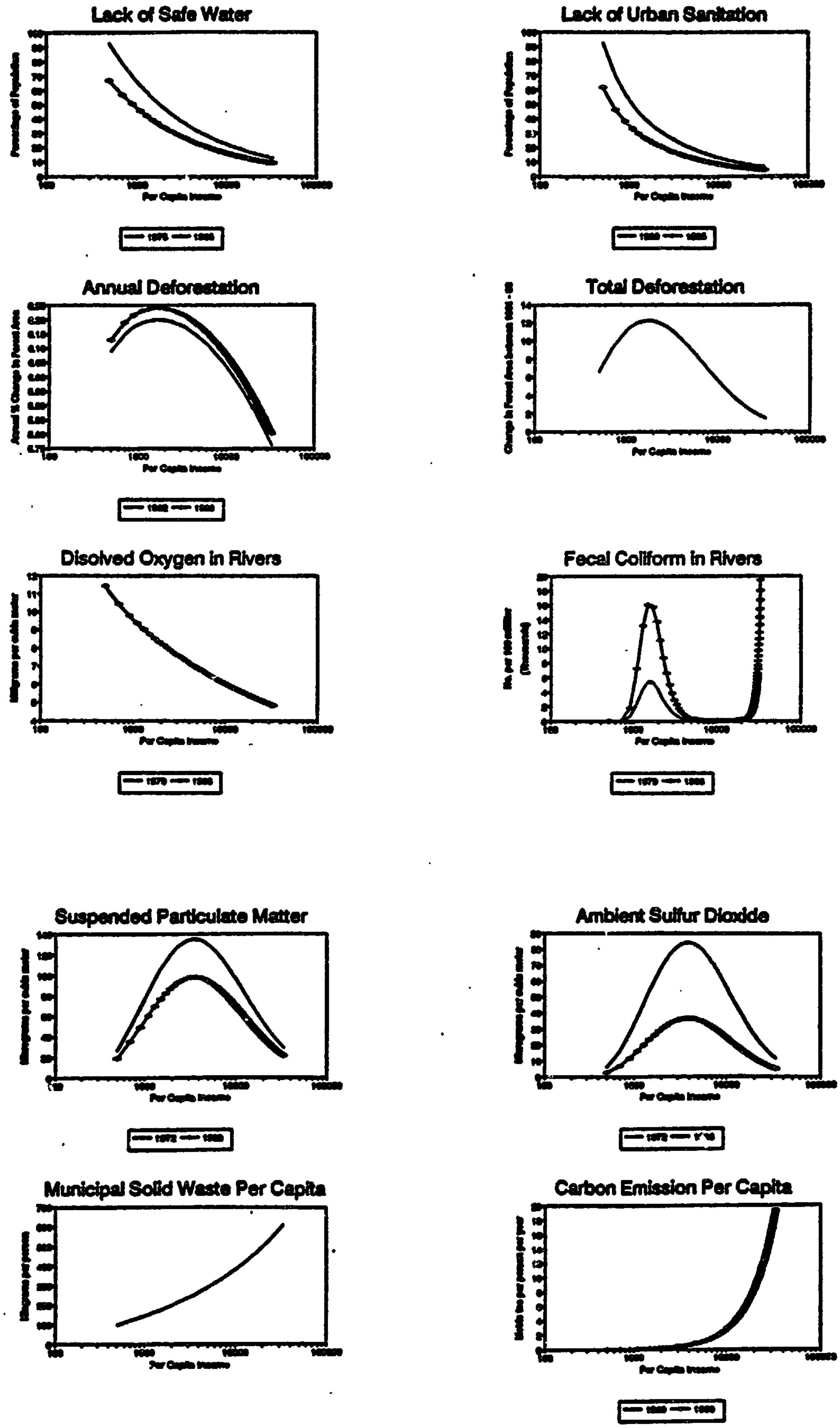

Figure 2 Changes in Environmental Elasticities with Income

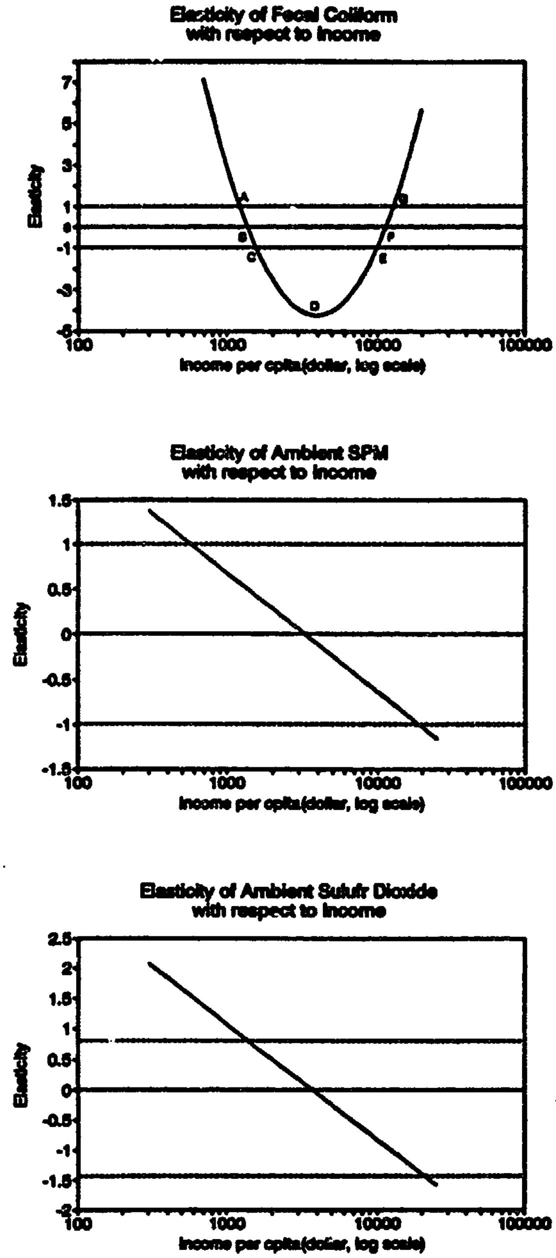

Table 1 Environment Indicators and Income (PPP)

Dependent Variables	Intercept*	Income	Income Squared	Income Cubed	Time Trend	Adjusted R Squared	Number of Observations
Lack of Safe Water	71.36	-0.48			-0.03	0.43	86
	(3.36)	(-7.36)			(-3.02)		
*	62.87	1.59	-0.14		-0.03	0.46	86
	(3.00)	(1.79)	(-2.34)		(-3.08)		
*	16.97	19.27	-2.49	0.10	-0.03	0.47	86
	(0.53)	(2.04)	(-1.98)	(1.86)	(-3.00)		
Lack of Urban Sanitation	169.10	-0.57			-0.08	0.22	123
	(2.43)	(-4.69)			(-6.36)		
*	167.53	1.07	-0.11		-0.08	0.22	123
	(2.41)	(0.82)	(-1.29)		(-6.36)		
*	87.35	27.37	-3.44	0.14	-0.08	0.24	123
	(1.12)	(2.29)	(-6.24)	(2.18)	(-6.28)		
Annual Deforestation	3.49	-0.02			0.00	-0.00	1511
	(0.78)	(0.77)			(0.63)		
*	0.64	0.65	-0.04		0.00	-0.00	1511
	(0.09)	(0.89)	(-0.88)		(0.61)		
*	15.57	-5.34	0.76	-0.04	0.00	-0.00	1511
	(0.64)	(-0.68)	(0.70)	(-0.74)	(0.23)		
Total Deforestation	2.99	-0.87				-0.01	58
	(0.04)	(0.68)					
*	-9.74	3.33	-0.23			-0.00	58
	(-0.96)	(1.22)	(-1.25)				
*	-41.42	16.04	-1.91	0.07		-0.02	58
	(-0.56)	(0.64)	(-0.49)	(0.43)			
Disolved Oxygen in Rivers	~	-0.18			0.00	0.99	506
		(-1.52)			(0.18)		
*	~	-1.46	0.08		0.00	0.99	566
		(-1.42)	(1.29)		(0.24)		
*	~	-11.55	1.34	-0.05	0.00	0.99	566
		(-0.96)	(0.92)	(-0.88)	(0.08)		
Fecal Coliform in Rivers	~	-1.87			0.17	0.96	402
		(-1.87)			(6.20)		
*	~	9.64	-0.74		0.17	0.96	402
		(1.29)	(-1.50)		(6.29)		
*	~	256.38	-31.47	1.27	0.12	0.96	402
		(2.77)	(-2.74)	(2.67)	(3.10)		
Ambient SPM	~	0.08			-0.03	1.00	764
		(0.53)			(-7.06)		
*	~	4.64	-0.29		-0.02	1.00	764
		(4.66)	(-4.62)		(-6.04)		
*	~	-8.09	1.26	-0.06	-0.02	1.00	764
		(-0.62)	(0.80)	(-0.98)	(-4.44)		
Ambient SO 2	~	0.17			-0.06	0.99	729
		(0.63)			(-9.09)		
*	~	6.81	-0.41		-0.05	0.99	729
		(3.79)	(-3.72)		(-7.40)		
*	~	37.20	-4.12	0.15	-0.05	0.99	729
		(1.38)	(-1.24)	(1.11)	(-7.38)		
Municipal Waste per capita	2.41	0.38				0.60	39
	(6.51)	(7.69)					
*	11.02	-1.70	0.13			0.63	39
	(2.50)	(-1.60)	(1.98)				
*	-33.96	15.08	-1.95	0.08		0.64	39
	(-0.88)	(1.08)	(-1.10)	(1.17)			
Carbon Emissions per capita	-15.46	1.62			0.00	0.85	3456
	(-6.27)	(137.12)			(0.59)		
*	-22.44	3.22	-0.10		0.00	0.85	3456
	(-7.60)	(22.02)	(-11.02)		(0.82)		
*	6.50	-6.91	1.17	-0.05	-0.00	0.86	3456
	(1.88)	(-6.48)	(6.80)	(-6.88)	(-0.01)		

Note: * Regressions without an intercept reported here include city and site or river dummies which allow each country to have its own intercept.

Table 2 Environment Indicators, Income (PPP), and Investment

Dependent Variables	Intercept*	Income	Income Squared	Income Cubed	Time Trend	Investment Shares	Adjusted R Squared	Number of Observations
Lack of Safe Water	72.92	-0.46			-0.03	-0.06	0.42	86
	(3.40)	(-8.42)			(-3.06)	(-0.61)		
Lack of Urban Sanitation	172.65	-0.55			-0.08	-0.06	0.21	123
	(2.45)	(-4.93)			(-2.34)	(-0.39)		
Annual Deforestation	3.36	0.14	-0.02		0.00	0.33	0.01	1509
	(0.25)	(0.18)	(-0.37)		(0.15)	(4.22)		
Total Deforestation	-9.41	3.31	-0.22			-0.22	-0.01	58
	(-0.91)	(1.20)	(-1.21)			(-0.81)		
Disolved Oxygen	~	-0.19			0.00	0.00	0.99	566
in Rivers		(-1.22)			(0.16)	(0.06)		
Fecal Coliform	~	248.96	-30.46	1.21	0.18	1.26	0.96	402
in Rivers		(2.70)	(-2.66)	(2.57)	(3.56)	(1.84)		
Ambient SPM	~	4.66	-0.28		-0.02	-0.09	1.00	764
		(4.86)	(-4.56)		(-6.03)	(-1.01)		
Ambient SO 2	~	6.36	-0.40		-0.05	0.31	0.99	729
		(3.51)	(-3.58)		(-5.80)	(1.66)		
Municipal Waste	2.31	0.33				0.19	0.61	39
per capita	(5.26)	(5.27)				(1.36)		
Carbon Emissions	-14.42	1.47			0.00	0.43	0.87	3454
per capita	(-5.26)	(115.27)			(0.19)	(22.50)		

Note: * Regressions without an intercept reported here include city and site or river dummies which allow each country to have its own intercept.

Table 3 Environment Indicators, Income (PPP), and Income Growth

Dependent Variables	Intercept*	Income	Income Squared	Income Cubed	Time Trend	Income Growth	Adjusted R Squared	Number of Observations
Lack of Safe Water	73.17	-0.47			0.03	1.00	0.43	86
	(3.44)	(-7.20)			(-3.10)	(1.08)		
Lack of Urban Sanitation	153.41	-0.61			-0.07	0.73	0.23	120
	(2.19)	(-5.96)			(-2.08)	(0.55)		
Annual Deforestation	-2.12	0.68	-0.05		0.00	0.49	-0.00	1508
	(-0.15)	(0.66)	(-0.91)		(0.43)	(0.67)		
Total Deforestation	-9.99	3.40	-0.23			0.65	-0.02	58
	(-0.96)	(1.22)	(-1.28)			(0.22)		
Disolved Oxygen in Rivers	~	-0.22			0.00	0.18	0.99	566
		(-1.71)			(0.28)	(0.76)		
Fecal Coliform in Rivers	~	245.32	-30.10	1.21	0.12	2.92	0.96	402
		(2.65)	(-2.62)	(2.55)	(3.22)	(1.60)		
Ambient SPM	~	4.68	-0.29		-0.02	-0.58	1.00	764
		(4.70)	(-4.60)		(-6.14)	(-2.37)		
Ambient SO 2	~	6.84	-0.42		-0.05	-0.05	0.99	725
		(3.79)	(-3.72)		(-7.06)	(-0.13)		
Municipal Waste per capita	2.01	0.42				2.87	0.64	39
	(4.37)	(8.31)				(2.16)		
Carbon Emissions per capita	-11.53	1.61			-0.00	-0.23	0.85	3401
	(-3.86)	(137.46)			(0.76)	(-1.23)		

Note: * Regressions without an intercept reported here include city and site or river dummies which allow each country to have its own intercept.

Table 4 Environment Indicators, Income (PPP), and Electricity Tariff.

Dependent Variables	Intercept*	Income	Income Squared	Income Cubed	Time Trend	Electricity Tariff	Adjusted R Squared	Number of Observations
Lack of Safe Water	7.68	-0.57				0.13	0.48	28
	(9.87)	(-5.16)				(1.11)		
Lack of Urban Sanitation	6.97	-0.42				-0.39	0.09	41
	(4.09)	(-1.90)				(-1.54)		
Annual Deforestation	155.85	-7.58	0.54		-0.06	-0.70	0.11	71
	(0.20)	(-1.57)	(1.61)		(-0.16)	(-2.61)		
Total Deforestation	-22.27	7.00	-0.48			-0.30	-0.00	36
	(-1.21)	(1.37)	(-1.36)			(-1.14)		
Disolved Oxygen in Rivers	~	0.00			-0.00	4.43	0.99	156
		(0.01)			(-0.22)	(0.31)		
Fecal Coliform in Rivers	~	836.93	-105.08	4.41	-0.32	-703.51	0.98	109
		(2.16)	(-2.11)	(2.06)	(-1.85)	(-1.70)		
Ambient SPM	~	49.63	-3.34		0.14	-492.93	0.99	91
		(1.89)	(-1.96)		(1.07)	(-1.57)		
Ambient SO 2	~	4.53	0.28		-0.63	1301.35	0.99	84
		(0.24)	(0.22)		(-6.70)	(5.63)		
Municipal Waste per capita	3.55	0.21				0.15	0.31	14
	(4.41)	(1.90)				(1.32)		
Carbon Emissions per capita	-43.01	1.59			0.02	-0.36	0.84	213
	(-0.67)	(33.46)			(0.47)	(-7.10)		

Note: * Regressions without an intercept reported here include city and site or river dummies which allow each country to have its own intercept.

Table 5 Environment Indicators, Income (PPP), and share of trade in GDP.

Dependent Variables	Intercept*	Income	Income Squared	Income Cubed	Time Trend	Trade Share in GDP	Adjusted R Squared	Number of Observations
Lack of Safe Water	68.65	-0.45			-0.03	-0.10	0.44	74
	(3.10)	(-5.63)			(-2.76)	(-0.97)		
Lack of Urban Sanitation	166.69	-0.54			-0.08	-0.18	0.22	98
	(2.15)	(-4.21)			(-2.06)	(-1.11)		
Annual Deforestation	-24.62	4.56	-0.30		0.01	-1.06	0.10	1248
	(-1.69)	(4.78)	(-4.59)		(0.64)	(-11.61)		
Total Deforestation	-21.94	6.58	-0.45			-0.32	0.05	47
	(-1.63)	(2.06)	(-2.11)			(-0.89)		
Disolved Oxygen in Rivers	~	-0.19			0.00	-0.01	0.99	452
		(-1.36)			(0.02)	(-0.20)		
Fecal Coliform in Rivers	~	272.48	-32.83	1.30	0.06	-0.34	0.96	313
		(2.43)	(-2.33)	(2.21)	(1.32)	(-0.56)		
Ambient SPM	~	4.82	-0.30		-0.03	0.14	1.00	461
		(3.35)	(-3.36)		(-4.78)	(1.54)		
Ambient SO 2	~	8.60	-0.51		-0.04	-0.49	0.98	465
		(3.62)	(-3.53)		(-4.86)	(-2.86)		
Municipal Waste per capita	2.27	0.39				-0.07	0.59	21
	(2.64)	(4.73)				(-0.79)		
Carbon Emissions per capita	-17.97	1.71			0.00	-0.01	0.80	2254
	(4.76)	(86.17)			(0.91)	(-0.26)		

Note: * Regressions without an intercept reported here include city and site or river dummies which allow each country to have its own intercept.

Table 6 Environment Indicators, Income (PPP) Parallel market premium

Dependent Variables	Intercept*	Income	Income Squared	Income Cubed	Time Trend	Parallel Market Premium	Adjusted R Squared	Number of Observations
Lack of Safe Water	82.01	-0.46			-0.04	-0.03	0.38	61
	(3.22)	(-5.46)			(-2.93)	(-0.96)		
Lack of Urban Sanitation	115.27	-0.47			-0.05	0.04	0.12	90
	(1.41)	(-3.57)			(-1.33)	(0.72)		
Annual Deforestation	45.81	1.53	-0.11		-0.02	-0.06	0.01	895
	(2.44)	(1.24)	(-1.30)		(-2.62)	(-1.92)		
Total Deforestation	-16.78	5.26	-0.36			0.05	0.02	41
	(-1.19)	(1.37)	(-1.39)			(0.62)		
Disolved Oxygen in Rivers	~	-0.23			0.00	-0.01	0.99	422
		(-1.56)			(0.23)	(-0.99)		
Fecal Coliform in Rivers	~	404.54	-49.27	1.98	-0.01	0.10	0.96	283
		(3.73)	(-3.64)	(3.53)	(-0.10)	(1.29)		
Ambient SPM	~	4.87	-0.30		-0.02	-0.01	1.00	373
		(2.36)	(-2.25)		(-3.72)	(-0.36)		
Ambient SO 2	~	10.77	-0.70		-0.03	0.04	0.99	377
		(3.96)	(-4.02)		(-3.06)	(1.49)		
Municipal Waste per capita	3.32	0.27				-0.02	0.66	16
	(6.74)	(4.77)				(-0.85)		
Carbon Emissions per capita	2.94	1.64			-0.01	0.07	0.80	1812
	(0.76)	(62.41)			(-4.37)	(7.61)		

Note: * Regressions without an intercept reported here include city and site or river dummies which allow each country to have its own intercept.

Table 7 Environment Indicators, Income (PPP), and Dollar's index of Openness

Dependent Variables	Intercept*	Income	Income Squared	Income Cubed	Time Trend	Dollar Index	Adjusted R Squared	Number of Observations
Lack of Safe Water	46.24	-0.44			-0.29	3.94	0.41	79
	(1.83)	(-6.06)			(-3.37)	(0.96)		
Lack of Urban Sanitation	209.53	-0.57			-0.07	-11.63	0.23	105
	(2.34)	(-3.74)			(-1.95)	(-1.25)		
Annual Deforestation	25.18	-3.97	0.29		-0.01	3.13	0.02	657
	(0.53)	(-2.41)	(2.56)		(-0.54)	(0.49)		
Total Deforestation	-11.63	0.60	-0.06			0.13	-0.04	60
	(-0.59)	(0.17)	(-0.23)			(0.78)		
Disolved Oxygen in Rivers	~	-0.27			-0.01	4.27	0.99	290
		(-1.12)			(-1.10)	(1.49)		
Fecal Coliform in Rivers	~	653.43	-86.29	3.77	0.32	-488.46	0.95	186
		(2.25)	(-2.23)	(2.11)	(3.52)	(-3.09)		
Ambient SPM	~	6.92	-0.39		-0.02	2.91	1.00	196
		(2.74)	(-2.59)		(-2.93)	(0.86)		
Ambient SO 2	~	-22.94	1.37		-0.01	26.10	0.98	198
		(-3.53)	(3.53)		(-0.65)	(3.03)		
Municipal Waste per capita	-6.75	0.26				2.19	0.55	19
	(-0.39)	(4.40)				(0.56)		
Carbon Emissions per capita	45.56	1.72			-0.00	-11.43	0.82	1113
	(3.56)	(81.16)			(-0.77)	(-6.61)		

Note: * Regressions without an intercept reported here include city and site or river dummies which allow each country to have its own intercept.

Table 8 Environment Indicators, Income (PPP) and Debt.

Dependent Variables	Intercept*	Income	Income Squared	Income Cubed	Time Trend	Debt Per Capita	Adjusted R Squared	Number of Observations
Lack of Safe Water	55.65	-0.48			-0.02	-0.03	0.40	82
	(2.05)	(-6.77)			(-1.79)	(-0.41)		
Lack of Urban Sanitation	145.90	-0.44			-0.07	0.02	0.11	114
	(1.84)	(-3.81)			(-1.75)	(0.11)		
Annual Deforestation	9.58	1.31	-0.08		-0.00	0.06	-0.00	892
	(0.31)	(1.01)	(-0.93)		(-0.29)	(0.63)		
Total Deforestation	-15.25	4.89	-0.34			-0.26	-0.02	54
	(-0.92)	(1.07)	(-1.07)			(-1.01)		
Disolved Oxygen in Rivers	~	-0.17			-0.01	0.06	0.99	403
		(-1.07)			(-0.90)	(0.95)		
Fecal Coliform in Rivers	~	529.73	-67.62	2.86	0.11	-0.12	0.95	270
		(2.75)	(-2.65)	(2.53)	(1.53)	(-0.22)		
Ambient SPM	~	7.70	-0.51		-0.01	0.04	1.00	295
		(2.40)	(-2.47)		(-0.58)	(-0.56)		
Ambient SO 2	~	19.70	-1.27		0.01	-0.27	0.99	729
		(3.93)	(-3.96)		(0.60)	(-2.36)		
Municipal Waste per capita	2.24	0.39				-0.19	0.34	14
	(2.06)	(2.94)				(-1.56)		
Carbon Emissions per capita	13.11	1.67			-0.01	0.16	0.81	1525
	(1.76)	(79.48)			(-3.65)	(7.39)		

Note: * Regressions without an intercept reported here include city and site or river dummies which allow each country to have its own intercept.

Table 9 Environment Indicators, Income (PPP), and Political Rights

Dependent Variables	Intercept*	Income	Income Squared	Income Cubed	Time Trend	Political Rights	Adjusted R Squared	Number of Observations
Lack of Safe Water	70.03	-0.47			-0.03	0.01	0.42	86
	(3.25)	(-6.78)			(-2.92)	(-0.42)		
Lack of Urban Sanitation	154.11	-0.42			-0.07	0.08	0.21	118
	(2.17)	(-4.56)			(-2.09)	(-1.59)		
Annual Deforestation	-0.12	0.82	-0.05		0.01	0.07	-0.00	762
	(-0.34)	(0.71)	(-0.64)		(0.42)	(1.81)		
Total Deforestation	-14.31	5.16	-0.38			-0.16	0.07	56
	(-1.23)	(1.56)	(-1.64)			(-1.53)		
Disolved Oxygen in Rivers	~	-0.19			0.00	0.03	0.29	409
		(-1.23)			(0.78)	(2.36)		
Fecal Coliform in Rivers	~	349.33	-42.35	1.69	0.08	-0.02	0.96	279
		(2.39)	(-2.30)	(2.21)	(1.36)	(-0.15)		
Ambient SPM	~	5.58	-0.34		-0.02	0.02	1.00	383
		(2.86)	(-2.80)		(-3.09)	(0.56)		
Ambient SO 2	~	12.41	-0.82		0.00	0.18	0.99	387
		(4.44)	(-4.72)		(0.04)	(3.35)		
Municipal Waste per capita	2.82	0.34				-0.02	0.62	21
	(4.20)	(4.57)				(-0.45)		
Carbon Emissions per capita	-10.88	1.16			0.00	-0.03	0.77	1357
	(-0.96)	(60.23)			(0.14)	(-2.57)		

Note: * Regressions without an intercept reported here include city and site or river dummies which allow each country to have its own intercept.

Table 10 Environment Indicators, Income (PPP), and Civil Liberties

Dependent Variables	Intercept*	Income	Income Squared	Income Cubed	Time Trend	Civil Liberties	Adjusted R Squared	Number of Observations
Lack of Safe Water	74.69	-0.45			-0.03	0.04	0.43	86
	(3.49)	(-6.67)			(-3.16)	(1.12)		
Lack of Urban Sanitation	179.75	-0.48			-0.09	0.11	0.20	117
	(2.46)	(-4.13)			(-2.40)	(1.60)		
Annual Deforestation	-1.21	1.61	-0.06		0.00	0.13	0.00	762
	(-0.4)	(0.92)	(-0.82)		(0.07)	(2.60)		
Total Deforestation	-15.53	5.49	-0.40			-0.18	0.06	56
	(-1.34)	(1.79)	(-1.96)			(-1.36)		
Disolved Oxygen in Rivers	~	-0.25			0.00	0.02	0.99	409
		(-1.54)			(0.24)	(0.97)		
Fecal Coliform in Rivers	~	263.72	-31.83	1.26	0.13	0.24	0.96	279
		(1.74)	(-1.67)	(1.59)	(2.06)	(1.50)		
Ambient SPM	~	5.66	-0.35		-0.02	0.02	1.00	383
		(2.93)	(-2.86)		(-3.56)	(0.64)		
Ambient SO 2	~	13.42	-0.88		-0.01	0.14	0.99	387
		(4.83)	(-5.07)		(-1.00)	(2.87)		
Municipal Waste per capita	3.63	0.24				0.04	0.65	21
	(8.40)	(5.36)				(0.98)		
Carbon Emissions per capita	-12.85	1.63			-0.00	0.03	0.84	1355
	(-1.41)	(75.57)			(-0.14)	(2.59)		

Note: * Regressions without an intercept reported here include city and site or river dummies which allow each country to have its own intercept.

Table 11 Environmental Elasticities - Income Effects

	Low Income	Middle Income	High Income
Lack of safe water	-0.48	-0.48	-0.48
Lack of urban sanitation	-0.57	-0.57	-0.57
Annual Deforestation	o	o	o
Total Deforestation	o	o	o
Dissolved oxygen	o	o	o
Fecal coliform	4.08	-4.20	-0.11
Ambient SPM	0.74	-0.03	-0.70
Ambient SO2	1.17	0.04	-0.93
Municipal waste per capita	0.38	0.38	0.38
Carbon emission per capita	1.62	1.62	1.62

Notes:
- The elasticities of environmental indicators with respect to income are calculated for - low, middle and high incomes defined as $900, $3500 and $11250 in PPP dollars respectively. These income groups represent the average PPP per capita income equivalents of the World Bank's country classifcaltion of low, middle and high income countries. Average low, middle and high per capita income levels are used to calculate elasticities based on the coefficient estimates of the best fitting model in table 1.

- o indicates the effects of the right hand side variable on the environmental indicator is not statistically significant at the 5 % level.

Table 12 Summary of Environmental Indicators, Income and Policy Effects

	Income	$Income^2$	$Income^3$	Time	Investment GDP	GDP Growth	Electricity Tariffs	Trade Share of GDP	Parallel Market Premium	Dollar Openness Index	Debt per capita	Political Rights	Civil Liberties
Lack of safe water	-	0	0	-	0	0	0	0	0	0	0	0	0
Lack of urban sanitation	-	0	0	-	0	0	0	0	0	0	0	0	0
Annual Deforestation	0	0	0	0	+	0	-	-	-	0	0	+	+
Total Deforestation	0	0	0	..	0	0	0	0	0	0	0	0	0
Dissolved oxygen	0	0	0	0	0	0	0	0	0	0	0	+	0
Fecal coliform	+	-	+	+	0	0	0	0	0	-	0	0	0
Ambient SPM	+	-	0	-	0	-	0	0	0	0	0	0	0
Ambient SO_2	+	-	0	-	+	0	+	-	0	+	-	+	+
Municipal waste per capita	+	0	0	..	0	+	0	0	0	0	0	0	0
Carbon emissions per capita	+	0	0	0	+	0	-	0	+	-	+	-	+

Notes: + means that an increase in the right hand side variable results in an increase in the environmental indicator at the 5% significance level.
- means that an increase in the right hand side variable results in a decrease in the environmental indicator at the 5% significance level.
0 indicates the right hand side variable has an insignificant effect on the environmental indicator.
.. not applicable.

Annex A

Data Sources and Definitions

Unless otherwise specified, the source of all data is the World Bank data base. Most of the variables cited here are included in the environmental data appendix to the World Development Report, 1992. Because of data limitations the actual sample size varied depending on availability. Whenever an indicator was not available for all sample countries in the period under consideration, a range of the number of countries is specified below. The sample size for each regression is specified in the last column of the relevant tables in the main text. All variables are in logarithms, unless otherwise specified.

Left Hand Side Variables:

Lack of safe water was measured by the percentage of population without access to safe drinking water. In urban areas access to safe water was defined as access to piped water or a public standpipe within 200 meters of a housing unit. In rural areas, it implies a family member need not spend a disproportionate part of the day fetching water. "Safe" drinking water includes untreated water from protected springs, boreholes and sanitary wells, as well as treated surface water. Data for this measure was available for only two years, 1975 and 1985 for 44 and 43 countries respectively. Source: World Bank. Bank Economic and Social Database (BESD).

Lack of urban sanitation was defined as percentage of urban population without access to sanitation. Access to sanitation was defined as urban areas served by connections to public sewers or household systems such as pit privies, pour-flush latrine, septic tanks, communal toilets and other such facilities. Data was available for 1980 and 1985 for 55 and 70 countries respectively. Source: World Bank, BESD.

Annual deforestation reflected the yearly change in forest area for 66 countries between 1962 and 1986. The variable was defined as

$$\log[FA_{n-1} - FA_{n}]$$

where FA is forest area in thousands of hectare and n takes value 1962 to 1986. Source: World Bank, BESD.

Total deforestation was the change in forest area between the earliest date for which substantial data was available, 1961, and the latest date, 1986. The variable was measured as

$$\log\left(\frac{(FA_{61} - FA_{86}) * 100}{FA_{61}}\right)$$

Total deforestation data was available for 77 countries. Source: World Bank, BESD.

Dissolved oxygen measured in milligrams per cubic meter, was available for 57 rivers distributed in 27 countries for intermittent years between 1979 and 1988. Dissolved oxygen measures the extent to which aquatic life can be supported. Low levels of dissolved oxygen can result from large amounts of industrial effluent or fertilizer runoff from adjacent agricultural land. Source: CCIW, 1991.

Fecal coliform measured in numbers per 100 milliliter, was available for 52 rivers distributed in 25 countries for intermittent years between 1979 and 1988. Fecal coliform measures the level of biological refuse in the river water. High levels of fecal coliform are associated with high incidence of water borne disease in the affected area. Data from five rivers were excluded from the sample due to extremely high reported levels of fecal coliform (exceeding 700,000 per 100 milliliter). These rivers are Atoyac, Balsas and Lerma in Mexico, San Pedro in Ecuador and Yodo in Japan. The effective sample size for fecal coliform was reduced from 434 to 402. Source: CCIW, 1991.

Sulfur dioxide. Data on ambient levels of sulfur dioxide measured in micrograms per cubic meter were available for 47 cities distributed in 31 countries for the years 1972 to 1988. Source: MARC, 1991.

Suspended particulate matter. Data on ambient levels of suspended particulate matter measured in micrograms per cubic meter were available for 48 cities in 31 countries for 1972 to 1988. Source: MARC, 1991.

Municipal solid waste per capita was computed in kilograms, on the basis of available city level information for 39 countries compiled for the year 1985. Source: OECD, 1991 and WRI, 1990.

Carbon emissions per capita was expressed in metric tons per person per year, for 118-153 countries between 1960 and 1989. Source: Marland, 1989.

Right Hand Side Variables:

Income per capita. Real per capita gross domestic product in purchasing power parity (PPP) terms were used for the years 1960 to 1988 for 95-138 countries (variable RGDPCH in Penn. World Table Mark 5.). The chain base method of indexing was used to take into account the changing production bundle over the period. GDP data was not available for all the countries for all the years. Source: Summers and Heston, 1991.

Investment as share of GDP. Investment data was from Summers and Heston, 1991 in PPP terms (variable I in Penn. World Tables Mark 5).

Growth of real income was derived as the log of the first difference, from the same per capita income variable and population estimates described above . Source: Summers and Heston, 1991.

Electricity tariff in US cents per kilowatt hour for 60 countries in 1987 was used as a proxy for energy prices in those countries between 1985 to 1988. Source: World Bank, 1990.

Trade share in GDP. Trade share was measured by total imports and exports of goods and non-factor services as a percentage of GDP. Data were available for 67-88 countries between 1960 and 1988. Source: World Bank, 1991.

Parallel market foreign exchange premia was based on the difference between official exchange rates and parallel market rates calculated as

$$PARALLEL = [\ (PMER - OER) / OER\ ]*100$$

where PMER is the parallel market exchange rate and OER is the official end of period exchange rate. The data was available for 36-99 countries for the years 1960 to 1988. Source: World Bank, 1991.

Dollar's outward orientation index for 87-90 countries between 1973 and 1985 as derived in Dollar, 1991. The index was computed by the weighted average of mean price distortion in the period 1973-85 and of its standard deviation. The price distortion was calculated as the residual of a regression of the relative price of consumption goods on urbanization, GDP per capita (a proxy for a country's endowment) and an interactive term. All variables were entered in logs, so that the residual could be interpreted as a percentage of deviation from an appropriate level as determined by the countries' endowment. Source: World Bank, 1991, also see Dollar, 1991.

Debt as a share of GDP for 83-119 developing countries between 1960 and 1988 was used from the Word Bank's database. Debt was defined as disbursed amounts of short and long term external liabilities outstanding and IMF credit. GDP was measured in 1987 US dollars.

Political rights index measures rights to participate meaningfully in the political process for 108-119 countries for 1973 and 1975-86 on a scale of one to seven where lower numbers indicate greater political rights (see Gastil, 1989). A high ranking country must have a fully operating electoral procedure, usually including a significant opposition vote. It is likely to have had a recent change of government from one party to another, an absence of foreign domination, decentralized political power and a consensus that allows all segments of the population some power. The index was constructed on the basis of satisfaction of the above and other related criteria by the countries in question. This variable is an index and not in logs. Source: Gastil, 1989. Also see World Bank, 1991.

Civil liberties index, measures the extent to which people are able to express their opinion openly without fears of reprisals and are protected in doing so by an independent judiciary. Though this index reflects rights to organize and demonstrate as well as freedom of religion, education, travel and other personal rights; more weight was given to those liberties that are most directly related to the expression of political rights. This variable is an index and not in logs. Source: Gastil, 1989. Also see World Bank, 1991.

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Annex B

A Cross-section Analysis of Income and Environmental Quality

This annex provides documentation for figure 4 and figure 1.5 of the World Development Report 1992 on the relationship between income levels and environmental quality for a cross secti~n of countries in the 1980s. The annex does not take into account time series effects that are explored through panel data in the main body of the paper. Figure 1.5 reports cross-section results for two different years for the lack of urban sanitation and ambient sulfur dioxides. Both these estimates are reported here.

Six indicators of environmental quality are considered: lack of safe water, lack of urban sanitation, ambient levels of suspended particulate matters, sulfur dioxide, generation of municipal solid waste, and per capita carbon emissions.

Three models were tested -- log linear, quadratic and cubic -- to establish the shape of the relationship between income and each environmental indicator. The cubic model did not add considerable explanatory power to any of the regressions, so it was dropped from the analysis. The model with the quadratic term was found to contribute significantly to the explanatory power of the regressions of the local air pollutants; that is, suspended particulate matter and sulfur dioxide concentrations. The log linear model was found to have the most explanatory power for regressions with all the other environmental indicators.

The two functional forms considered, the log linear and quadratic, are:

a) $\log(E) = \alpha + \beta \log(Y)$

b) $\log(E) = \alpha + \beta_1 \log(Y) + \beta_2 \log(Y)^2$

where E is the respective environmental indicator and Y is the per capita income variable described below. Cross section analysis for deforestation and indicators of river quality were not reported due to data limitations. The actual sample size varied depending on data availability. Unless otherwise specified, the source of all data is the World Bank data base. The best fits for the cross-section results, those that are represented in the figures in World Development Report 1992, are reported below.

Right Hand Side Variable: Real per capita gross domestic product in purchasing power parity (PPP) terms were used for the years between 1976 and 1988 for 39-135 countries (variable RGDPCH in Penn. World Table Mark 5.). The chain base method of indexing was used to take into account the changing production bundle over the period. The range of years and the actual sample size of countries were dependent on data availability. Data source: Summers and Heston, 1991.

Left Hand Side Variables:

Lack of safe water was measured by the percentage of population without access to safe drinking water. Access to safe water was defined as access to piped water or a public standpipe within 200 meters of a housing unit,in an urban areas. In rural area, it implies a family member need not spend a disproportionate part of the day fetching water. "Safe" drinking water includes untreated water from protected springs, boreholes and sanitary wells, as well as treated surface water. Data for the year 1985 for 43 countries was regressed on per capita income and th log linear model provided the best fit:

1. $\log(\text{no safe water}) = 7.6507 - 0.5423 * \log(Y)$
   (9.78) (-5.16) Adjusted $R^2=0.38$

Data source: World Bank. Bank Economic and Social Database (BESD).

Lack of urban sanitation was defined as the percentage of urban population without access to sanitation. Access to sanitation was defined as urban areas served by connections to public sewers or household systems such as pit privies, pour-flush latrine, septic tanks, communal toilets and other such facilities. Two sets of cross-section estimates were made using log linear model for 1980 and 1985 for 55 and 70 countries respectively.

2. 1980:log(no sanitation) = 7.4640 - 0.5269 * log(Y)
(7.65) (-4.12)Adjusted R^2=0.23

3. 1985:log(no sanitation) = 7.6434 - 0.6051 * log(Y)
(6.69) (-3.96)Adjusted R^2=0.19

Data source: World Bank. BESD

Suspended particulate matter (SPM) Data on ambient levels of suspended particulate matter measured in micrograms per cubic meter were available for 35 cities in 21 countries for 1985. Data for ambient particulate levels was available disaggregated by city and site. Sites were divided between residential, commercial as well as by location classifications such as city center and suburbs. City dummies were used in the quadretic model to take location specific effects into account.

b1) $\log(E) = \alpha_i + \beta_1 \log(Y) + \beta_2 \log(Y)^2$

where α_i are coefficients of the intercept dummy for the i^{th} city. To obtain a relationship between income and ambient levels of SPM that is independent of the city location effects, α was defined as the weighted mean of α_i. Where the weights were the proportion of the number of observations from the i^{th} city in the sample. The equation used to predict SPM concentrations for different income levels in 1985 were:

4. log(SPM) = 0.17 + 2.76 * log(Y) - 0.26 * $\log(Y)^2$
(13.01) (-9.81) Adjusted R^2=0.56

Data source: MARC, 1991.

Sulfur dioxide. Data on ambient levels of sulfur dioxide measured in micrograms per cubic meter were available for 25 cities in 18 countries for 1976 and for 31 cities in 21 countries for 1985. To take into account the location specific effects of different sites, the quadretic model was modified, so that:

b2) $\log(E) = \alpha_j + \beta_1 \log(Y) + \beta_2 \log(Y)^2$

where α_j coefficients of intercept dummy for the j^{th} site type. To obtain a relationship between income and SO_2 emissions, that is independent of the site effects, α was defined as the weighted mean of α_j. Where the weights were the proportion of the number of observations from the j^{th} site type in the sample. The final equation used to predict SO_2 emissions for different income levels in 1976 and 1985 were:

5. 1976: $\log(SO_2) = -1.50 + 1.46 * \log(Y) - 0.10 * \log(Y)^2$
(—) (0.24) (-0.27) Adjusted $R^2=0.94$

6. 1985: $\log(SO_2) = -6.35 + 2.77 * \log(Y) - 0.19 * \log(Y)^2$
(—) (1.74) (-1.93) Adjusted $R^2=0.97$

Data source: MARC, 1991.

Municipal solid waste per capita was computed in kilograms, on the basis of available city level information for 39 countries compiled for the year 1985. A simple average was used when data for more than one city in the same country was available. Three centrally planned economies, Bulgaria, Hungary and Poland were dropped from the sample because of data inconsistency.

7. $\log(\text{waste}) = 2.4122 + 0.3844 * \log(Y)$
(5.51) (7.69) Adjusted $R^2=0.60$

Data source: OECD, 1991 and WRI, 1990.

Carbon emissions per capita was expressed in metric tons per person per year, for 135 countries for the year 1985. Estimates of national carbon emissions were based on consumption of fossil fuels in gas, liquid and solid forms and do not include carbon emissions from oxidization of bio-mass. Carbon emissions was regressed on per capita income using the log linear model.

8. log(per capita carbon) = -13.4848 + 1.5625 * log(Y)
(-35.31) (32.49) Adjusted R^2=0.89

Data source: Marland, 1989.

Remarks

To generate the graphs reported in the World Development Report (1992), an uniform distribution of income was generated starting from 100 PPP dollars to 33,000 PPP dollars, with a constant interval of 200 dollars. This uniform distribution does not represent real countries, but rather is a hypothetical range of incomes a country might have. The minimum and the maximum values of this distribution were chosen to cover the range of observed income of the poorest and the richest countries in the sample. The uniform distribution was suitably transformed using equations 1 through 8, to arrive at the predicted levels of each environmental indicator for any given level of per capita income. These predicted values of the environmental indicators derived from equations 1 through 8 are graphically presented in Figure B.1 and Figure B.2 of this annex.

The results presented above were found to be consistent with the broader findings based on panel data in Shafik and Bandyopadhyay, 1992. In general, the panel results were more robust than the cross-section ones. Uneven sampling determined by availability of data lead to increases in the variance of the estimated coefficients when cross-section samples from different years were used.

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